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MR findings associated with positive distraction of the hip joint achieved by axial traction

Suter, Aline ; Dietrich, Tobias J ; Maier, Matthias ; Dora, Claudio ; Pfirrmann, Christian W A

Abstract: PURPOSE: To determine which MR-arthrography findings are associated with positive hip joint distraction. MATERIALS AND METHODS: One hundred patients with MR arthrography of the hip using axial traction were included. Traction was applied during the MR examination with an 8 kg (females) or 10 kg (males) water bag, attached to the ankle over a deflection pulley. Fifty patients showing joint space distraction were compared to an age- and gender-matched control group of 50 patients that did not show a joint distraction under axial traction. Two radiologists assessed the neck-shaft angle, lateral and anterior center-edge (CE) angles, CE angles in the transverse plane, extrusion index of the femoral head, acetabular depth, alpha angle, acetabular version, ligamentum teres, joint capsule and ligaments, iliopsoas tendon and the labrum. RESULTS: Mean joint space distraction in the study group was 0.9 ± 0.6 mm. Patients with positive joint space distraction had significantly higher neck-shaft angles (control group 131.6 ± 5.4°/study group 134.1 ± 6.1°, $p < 0.05$), smaller lateral CE angles (38.1 ± 5.9°/34.6 ± 7.2°, $p < 0.05$), smaller overall transverse CE angles (161.4 ± 9.9°/153.6 ± 9.6°, $p < 0.001$), smaller acetabular depth (4.1 ± 2.4 mm/5.8 ± 2.5 mm, $p < 0.01$), higher alpha angles (53.5 ± 7.8°/59.2 ± 10.1°, $p < 0.01$) and a thicker ligamentum teres (4.7 ± 1.4 mm/5.4 ± 1.8 mm, $p < 0.05$). The other parameters revealed no significant differences. ICC values for interobserver agreement were 0.71-0.95 and kappa values 0.43-0.92. CONCLUSION: Increased neck-shaft angles, small CE angles, small acetabular depth, higher alpha angles and a thick ligamentum teres are associated with positive joint distraction.

DOI: https://doi.org/10.1007/s00256-015-2099-3

Posted at the Zurich Open Repository and Archive, University of Zurich
ZORA URL: https://doi.org/10.5167/uzh-111711
Journal Article
Published Version

Originally published at:
Suter, Aline; Dietrich, Tobias J; Maier, Matthias; Dora, Claudio; Pfirrmann, Christian W A (2015). MR findings associated with positive distraction of the hip joint achieved by axial traction. Skeletal Radiology, 44(6):787-795.
DOI: https://doi.org/10.1007/s00256-015-2099-3

Skeletal Radiol (2015) 44:787–795
DOI 10.1007/s00256-015-2099-3

SCIENTIFIC ARTICLE

MR findings associated with positive distraction of the hip joint achieved by axial traction

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Received: 2 September 2014 / Revised: 4 January 2015 / Accepted: 5 January 2015 / Published online: 27 January 2015
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Abstract
Purpose To determine which MR-arthrography findings are associated with positive hip joint distraction.
Materials and methods One hundred patients with MR arthrography of the hip using axial traction were included. Traction was applied during the MR examination with an 8 kg (females) or 10 kg (males) water bag, attached to the ankle over a deflection pulley. Fifty patients showing joint space distraction were compared to an age- and gender-matched control group of 50 patients that did not show a joint distraction under axial traction. Two radiologists assessed the neck-shaft angle, lateral and anterior center-edge (CE) angles, CE angles in the transverse plane, extrusion index of the femoral head, acetabular depth, alpha angle, acetabular version, ligamentum teres, joint capsule and ligaments, iliopsoas tendon and the labrum.
Results Mean joint space distraction in the study group was 0.9±0.6 mm. Patients with positive joint space distraction had significantly higher neck-shaft angles (control group 131.6±5.4°/study group 134.1±6.1°, $p<0.05$), smaller lateral CE angles (38.1±5.9°/34.6±7.2°, $p<0.05$), smaller overall transverse CE angles (161.4±9.9°/153.6±9.6°, $p<0.001$), smaller acetabular depth (4.1±2.4 mm/5.8±2.5 mm, $p<0.01$), higher alpha angles (53.5±7.8°/59.2±10.1°, $p<0.01$) and a thicker ligamentum teres (4.7±1.4 mm/5.4±1.8 mm, $p<0.05$). The other parameters revealed no significant differences. ICC values for interobserver agreement were 0.71–0.95 and kappa values 0.43–0.92.
Conclusion Increased neck-shaft angles, small CE angles, small acetabular depth, higher alpha angles and a thick ligamentum teres are associated with positive joint distraction.

Keywords Hip Joint · Arthrography · Magnetic Resonance Imaging · Traction · Joint instability · Microinstability · Atraumatic instability

Abbreviations and acronyms

N	Newton
MR	magnetic resonance
TR	repetition time
TE	echo time
FOV	field of view
FSE	fast spin-echo
DESS	double echo steady state
FISP	fast imaging with steady-state precession
PACS	picture archiving and communication system
CE	centre edge
SBILFL	superior band of the iliofemoral ligament
IBILFL	inferior band of the iliofemoral ligament
ICC	intraclass correlation coefficient
n/a	not applicable

Introduction

Atraumatic instability of the hip, also known as microinstability, is defined by two elements. The first element is laxity of the hip joint with the inability to keep the femoral

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head centered within the acetabular fossa, typically without complete luxation or marked subluxation of the joint. The second element is the presence of symptoms, such as pain or unsteadiness [1, 2].

Atraumatic hip instability may be associated with generalized laxity, connective tissue disorders (such as Marfan's or Ehlers Danlos), mild osseous hip dysplasia not meeting the radiographic criteria, repetitive microtrauma caused by overuse or supraphysiologic range of motion [1]. This leads to damage to the labrum, cartilage or ligaments, which promotes translation of the femoral head rather than contained rotation within the acetabulum. The translation of the femoral head even leads to further damage of these structures [1, 2].

Atraumatic instability of the hip is an evolving topic that receives considerable attention in the current orthopedic literature, however without valid clinical, imaging or surgical criteria for the diagnosis [2, 3]. Clinical tests such as the dial test, traction test or posterior impingement test have been described as useful examinations [3]. For the dial test, the leg is internally rotated and then released in the supine patient. If the limb falls into external rotation more than 45° from the vertical position, the test is positive and indicative of capsular laxity [4]. In patients with atraumatic instability, traction of the hip may demonstrate apprehension, which is a suggestive clinical sign of instability [3]. The posterior impingement test is performed with extension and external rotation of the hip, provoking the typical pain [5].

Because of the absence of valid clinical or surgical criteria, a positive hip joint distraction achieved with axial traction forces well below the forces needed to distract a normal hip joint was used as a model for laxity of the hip joint for this work. According to the literature more than 200–400 Newton (N) is needed to distract a hip joint [6, 7].

A positive hip joint distraction achieved by a distraction force of less than 100 N (80–100 N) was used as reference standard in the present study.

It was hypothesized that various imaging parameters might be associated with positive joint distraction at traction MR arthrography. Thus, the purpose of this study was to determine which MR-arthrography findings are associated with positive hip joint distraction.

Materials and methods

Patients

A total of 1,188 consecutive traction MR arthrograms of the hip were retrospectively reviewed for this study. The patients were referred for MR arthrography because of hip pain clinically caused by an internal derangement of the joint and to assess the joint structures such as the labrum and cartilage. MR arthrography with traction was the single institution's standard protocol. Patients with previous surgery of the hip, fractures or other trauma, congenital hip dysplasia, full thickness cartilage defects, neoplasm and age younger than 18 years were excluded (n=445). This resulted in 743 consecutive traction MR arthrograms of the hip with a mean age of 37.9 years and an age range between 18.2 and 71.5 years (397 hip joints of female patients, 346 hip joints of male patients).

All patients gave written permission for anonymized use of their medical data for scientific purposes before the imaging examination. The study was submitted to the institutional review board, and a waiver for additional approval was issued for this study.

Study and control groups

A medical student in the final year (AS) screened and allocated all patients in consensus with a board-certified musculoskeletal radiologist (TJD, 3 years of experience in musculoskeletal radiology) and a senior musculoskeletal radiologist (CWAP, 14 years of experience in musculoskeletal radiology). Out of the 743 consecutive traction MR arthrograms, the first 50 patients with a positive hip joint distraction (36 hip joints of female patients, 14 hip joints of male patients) were allocated to the study group. Distraction was defined as a separation of the femoral and acetabular cartilage layer, visible in the coronal and sagittal plane. In this model distraction was an "all or nothing" phenomenon without a further grading.

Eleven patients with positive joint distraction were used for a training session and not included in the analysis (11/61). For the control group 50 age- and gender-matched patients without distraction at traction MR arthrography were selected. The matched controls were chosen blinded to their imaging findings. The mean patient age in the study group was 41.2 years (range, 20.6–68.3 years) and 41.0 years (range, 21.3–71.2 years) in the control group.

Imaging protocol

All patients underwent fluoroscopically guided intraarticular injection of 1 ml lidocaine 2 % (Rapidocain; Sintetica SA, Mendrisio, Switzerland), 1 ml of an iodinated contrast agent (Iopamidol 200 mg/ml, Iopamiro 200; Bracco, Milan, Italy) and 8–12 ml of 2 mmol/l MR contrast agent (gadopentetate dimeglumine solution, Magnevist, Bayer HealthCare, Berlin, Germany) [8]. Subsequently, patients were examined in one of three 1.5-T MR scanners (Magnetom Symphony, Magnetom Espree and Magnetom Avanto, Siemens Medical Solutions, Erlangen, Germany), depending on availability. Axial traction was applied during the whole MR examination with an 8 kg (for females) or 10 kg (for males) water bag, attached to the ankle over a deflection pulley (Fig. 1), according to forces between approximately 80–100 N. This protocol was

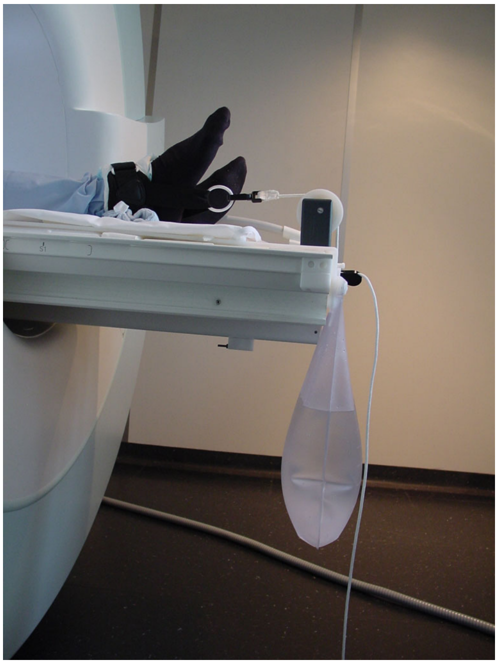


Fig. 1 Traction device: Axial traction was applied during the MR examination with an 8–10-kg water bag, attached to the ankle over a deflection pulley

performed in all 1,188 patients, disregarding the physical condition of the patient. The following sequences represent our standard MR-arthrography protocol and were obtained with a body matrix phased-array coil anteriorly and a spine array coil posteriorly: Coronal and sagittal T1-weighted fast spin-echo [repetition time ms (TR)/echo time msec (TE), 605/13 for coronal images and 550/13 for sagittal images; field of view (FOV), 160×160 mm; matrix, 512×256; section thickness, 3 mm for coronal and 4 mm for sagittal images), coronal intermediate-weighted fast spin-echo (FSE) with fat suppression (TR/TE, 3,540/39; FOV, 160×160 mm; matrix, 256×256; section thickness, 3 mm), sagittal 3D water-excitation double-echo steady-state (DESS) (TR/TE, 25.16/8.56; FOV, 150×150 mm; matrix, 256×192; section thickness, 1.7 mm) and transverse oblique 3D water-excitation true fast imaging with steady-state precession (trueFISP) MR images parallel to the longitudinal axis of the femoral neck with secondary radial reformations along the longitudinal line of the femoral neck as the rotation axis (TR/TE, 12.3/5.45; FOV, 170×170 mm; matrix 384×384, section thickness, 1.25 mm).

Image analysis

Two independent musculoskeletal radiologists (TJD, MM, with 3 and 10 years of experience) reviewed the 100 MR examinations separately. All measurements were taken using electronic calipers on a picture archiving and communication system (PACS) workstation (AGFA Impax 6.4.0.4551, Agfa HealthCare, Mortsel, Belgium). After a training session with 11 patients excluded from the analysis, the readers were free to choose the images on which the measurements were taken. Both radiologists were informed about the purpose of the study and the criteria of patient's study and control group assignment. MR arthrograms were analyzed consecutively in the order of the acquisition date. The radiologists were not informed about whether the MR arthrograms belonged to the study or control group.

The following MR criteria were assessed:

Joint distraction was measured in mm as the distance between the cartilage layer of the femoral head and acetabulum at the most proximal point of the femoral head on coronal and sagittal images. Joint distraction was measured on coronal and sagittal images to minimize partial volume effects.

The neck-shaft angle was measured between the longitudinal axes of the femoral neck and shaft on coronal images.

The lateral and anterior CE angles [9, 10] were measured on coronal (lateral CE angle; Figs. 2a and 3a–b) and sagittal (anterior CE angle; Fig. 2b) images according the technique for anteroposterior and false profile view conventional radiographs.

The CE angles in the transverse plane were determined on transverse images anteriorly and posteriorly. The overall transverse CE angle was determined by calculating 180° - anterior CE angle + posterior CE angle (Figs. 2c and 3c-d).

The extrusion index of the femoral head was quantified as a ratio on coronal images by measuring the distance of the lateral part of the femoral head that is not roofed by the acetabulum divided by the total width of the femoral head [11–14] as illustrated in Fig. 2d.

The acetabular depth was measured on transverse oblique images by connecting the anterior acetabular rim to the posterior acetabular rim with a line and measuring the distance between this line and the center of the femoral head as previously illustrated by Pfirrmann et al. [15] (Figs. 2e and 3e–f).

The alpha angle served for quantification of the osseous deformities at the femoral head-neck junction [16, 17]. The alpha angle was measured as the axis between the femoral neck and the line from the center of the femoral head to the point where the distance from the center of the femoral head exceeds the radius of the femoral head [15, 16]. The maximum alpha angle was measured on the radial plane image with the most severe cam impingement configuration (Fig. 3g–h).

The acetabular version was measured on transverse images at the superior, midportion and inferior level by connecting the anterior acetabular rim to the posterior

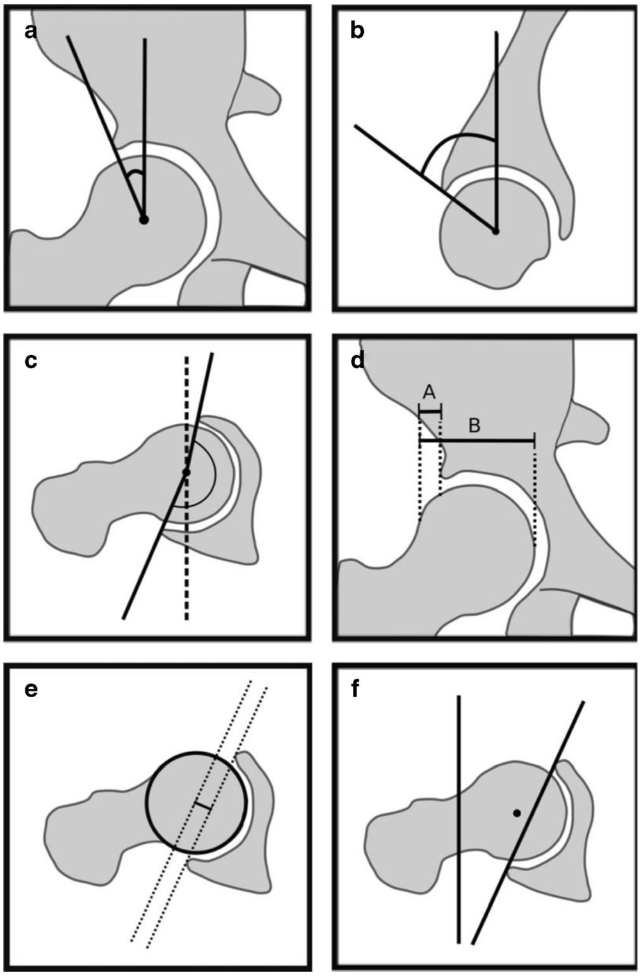


Fig. 2 Measurements: CE angle coronal plane (**a**) and CE angle sagittal plane (**b**) according the technique on anteroposterior and false profile view conventional radiographs. The overall transverse CE angle was determined on transverse images anteriorly and posteriorly by calculating 180° - anterior CE angle+posterior CE angle (**c**). The extrusion index as the ratio of the part of the femoral head not covered by the acetabulum divided by the total width of the femoral head (**d**), acetabular depth as the distance between two parallel lines connecting the acetabular rim anterior to posterior and through the center of the femoral head (**e**), and acetabular version by measuring the angle between the lines connecting the anterior to posterior acetabular rim and the sagittal plane (**f**)

acetabular rim with a line and measuring the angle to the sagittal plane (Fig. 2f).

Ligamentum teres: The thickness of the ligamentum teres was determined 5 mm distal to its insertion at the femoral head [16] on coronal images. The ligamentum teres was classified as normal or abnormal. The following findings were considered abnormal: fraying of the substance, partial or complete tear, hypoplasia or absence [18, 19].

Joint capsule and ligaments: The following characteristics of the capsular ligaments were assessed [20]: the thickness of the superior band of the iliofemoral ligament (SBILFL) at its midportion on coronal images, thickness of the inferior band of the iliofemoral ligament (IBILFL) at its midportion on sagittal images and thickness of the zona orbicularis in the anteroposterior (ap) direction on transverse images.

The iliopsoas tendon was assessed for edema, bursitis and thickness.

The labrum was determined as normal or abnormal at its anterior (10 o'clock position), superior (12 o'clock position) and posterior (2 o'clock position) location. A tear was defined as labral detachment or a linear, Y-shaped as well as irregular contrast material penetration into the labral substance. Degeneration was defined as signal alteration or a blunted labrum. The size of the labrum at all three locations was measured as the shortest mediolateral distance.

Statistical analysis

For quantitative values the Student's t-test and for qualitative values the Fisher's exact test was used. $P<0.05$ was considered indicative of a statistically significant difference between the control and study group.

Interobserver agreement was quantified by using the intraclass correlation coefficient (ICC) for quantitative values and Cohen's kappa coefficient for qualitative data [21–23].

A computer software package (SPSS for Windows, release 17.0; SPSS, Chicago, IL) was used for statistical calculations.

Results

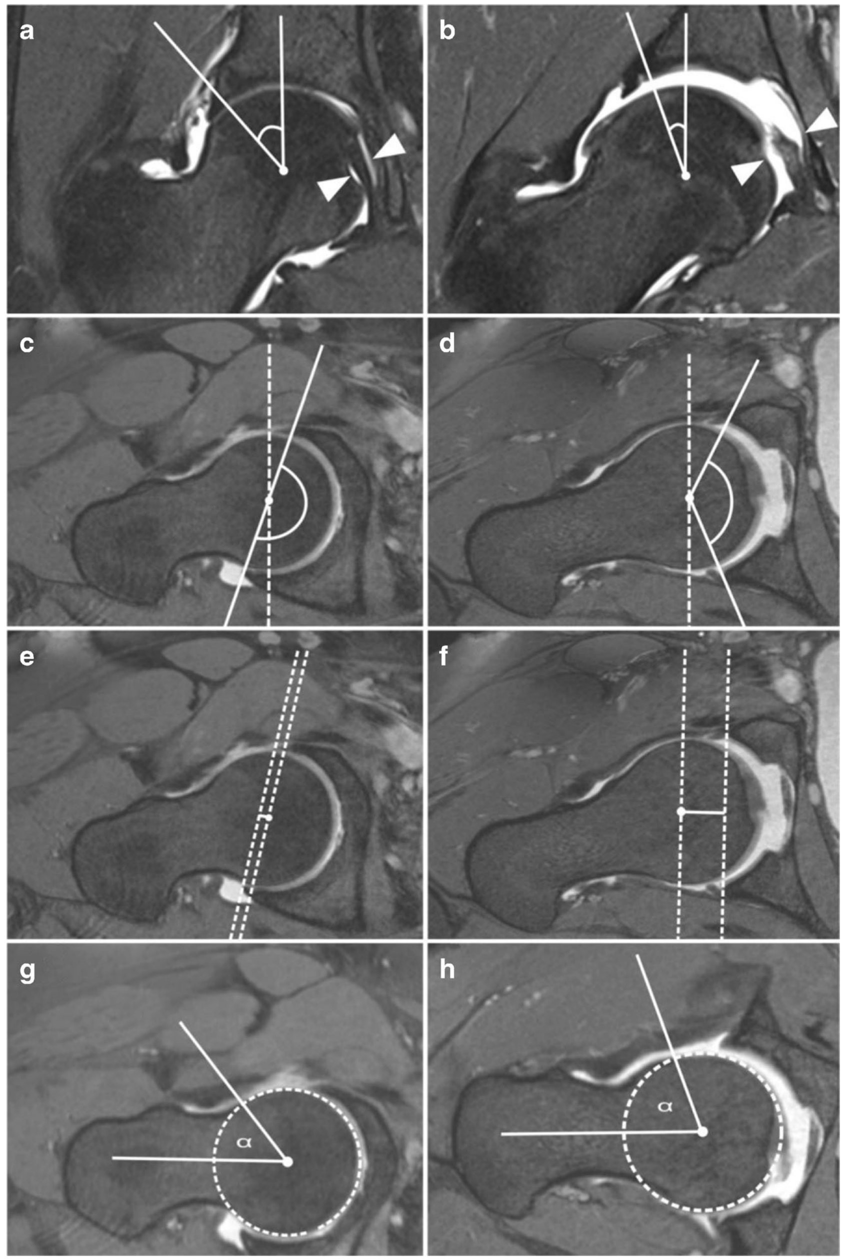
Eight percent ($n=61$) of 743 consecutive traction MR traction arthrograms of the hip showed a positive joint distraction. Mean joint space distraction in the study group ($n=50$) for observer 1 was: coronal 0.9±0.6 mm/sagittal 0.9±0.6 mm; observer 2: coronal 1.0±0.5 mm/sagittal 1.0±0.5 mm; ICC= 0.83. Measurements for positive joint distraction in the study group showed a spectrum with a minimum value of 0.3 mm and a maximum of 3.5 mm.

Tables 1 and 2a summarize the quantitative parameters.

Patients with positive joint space distraction had significantly higher neck-shaft angles compared to the control group (observer 1: control group 131.6±5.4°/study group 134.1± 6.1°, $p<0.05$). The following CE angles were significantly smaller in the study group: lateral CE angle (observer 1: 38.1±5.9°/34.6±7.2°, $p<0.05$), posterior transverse CE angle (observer 1: 7.7±7.1°/2.3±8.2°, $p<0.01$) and the overall transverse CE angle (observer 1: 161.4±9.9°/153.6±9.6°, $p<0.001$). The anterior CE angle and anterior transverse CE angle were not significantly different between the two groups (Table 1).

The extrusion index showed no significant difference between the two groups (Table 1). Both observers assessed a

Fig. 3 MR traction arthrography of the right hip without joint space distraction (control group; left images; **a**, **c**, **e**, **g**) and with positive joint space distraction (study group; right images; **b**, **d**, **f**, **h**) of two 26-year-old females. Coronal intermediate-weighted FS (**a, b**), transverse oblique 3D true FISP (**c**, **d**, **g**, **h**) and radial reconstructed 3D true FISP MR images (**e**, **f**) demonstrate the smaller lateral CE angles (**b**), thicker ligamentum teres (**b**, white arrows), smaller overall transverse CE angle (**d**), smaller acetabular depth (**f**) and higher alpha angle (**h**) in the study group.



significantly smaller acetabular depth (observer 1: 4.2±2.4 mm/5.8±2.5 mm, p<0.01) and higher alpha angle in the study group (observer 1: 53.5±7.8°/59.2±10.1°, p<0.01) (Table 1).

The acetabular version (superior, midportion, inferior) showed no significant difference between the two groups (Table 1).

All measurements of the joint capsule and ligaments (thickness of the SBILFL and IBILFL, thickness of the zona orbicularis) revealed no significant differences between the two groups (Table 2a).

The ligamentum teres in the study group was significantly thicker than in the control group (observer 1: 4.7±1.4 mm/5.4±1.8 mm, p<0.05) (Table 2a). Ligamentum teres abnormalities showed no significant differences between the two groups (Table 2b).

Observer 2 assessed a significant difference regarding the thickness of the iliopsoas tendon (4.5±0.8 mm/4.2±0.6 mm, p<0.05), whereas observer 1 found no significant differences (4.4±0.9 mm/4.3±0.9 mm, p=0.67) (Table 2a). The other variables for the iliopsoas psoas tendon showed no significant difference between the two groups (Table 2b).

Both observers assessed no significant differences regarding tears or degeneration of the labrum between the two groups (Table 2b).

Table 1 Bone

	Observer 1			Observer 2			ICC	
	Control group (mean±SD)	Study group (mean±SD)	p-value	Control group (mean±SD)	Study group (mean±SD)	p-value	Control group	Study group
Neck-shaft angle [°]	131.6±5.4	134.1±6.1	<0.05	131.9±4.5	134.6±5.5	<0.01	0.81	0.84
CE angle coronal plane [°]	38.1±5.9	34.6±7.2	<0.05	36.6±6.1	33.8±7.3	<0.05	0.92	0.92
CE angle sagittal plane [°]	61.1±6.4	60.1±6.7	0.39	60.7±5.9	59.3±6.4	0.19	0.93	0.95
CE angle transverse plane anterior [°]	26.3±6.5	28.6±6.6	0.07	26.5±6.0	28.5±6.5	0.09	0.95	0.94
CE angle transverse plane posterior [°]	7.7±7.1	2.3±8.2	<0.01	7.4±7.1	1.8±8.7	<0.01	0.95	0.94
CE angle overall transverse [°]	161.4±9.9	153.6±9.6	<0.001	160.9±9.6	153.2±10.0	<0.001	0.93	0.94
Extrusion index	0.098±0.055	0.107±0.084	0.55	0.106±0.063	0.121±0.097	0.33	0.87	0.94
Acetabular depth [mm]	4.1±2.4	5.8±2.5	<0.01	4.4±2.4	6.1±2.5	<0.01	0.91	0.91
Alpha angle [°]	53.5±7.8	59.2±10.1	<0.01	53.6±7.8	58.3±8.7	<0.01	0.92	0.91
Acetabular version [°]								
Superior	3.2±7.3	2.1±7.9	0.42	3.0±7.3	2.1±7.4	0.52	0.94	0.94
Midportion	17.0±4.4	15.1±5.4	0.08	17.0±4.6	15.7±4.9	0.20	0.95	0.94
Inferior	16.2±5.2	15.9±5.9	0.77	16.6±4.8	16.2±5.2	0.68	0.88	0.85

The measurements of both observers revealed ICC values between 0.71–0.95 and kappa values between 0.43–0.92.

Discussion

Atraumatic instability or microinstability of the hip is a new and evolving concept [1, 2]. Atraumatic instability can be idiopathic but is also reported in patients with hip dysplasia, patients with ligamentous laxity or high-performance athletes [2]. Instability of the hip joint is a possible reason for hip pain. Atraumatic instability of the hip joint is increasingly discussed in the orthopedic literature [24, 25], but there are only limited data or reports on the diagnostic criteria. Clinical examination for the assessment of atraumatic instability of the hip is often non-specific [19, 26, 27]. The classification of hip instability has evolved in recent times. Hip instability can be classified in traumatic or atraumatic causes. A traumatic event as a reason for the instability tends to be rather rare. Overuse instability in athletes could be included as traumatic because of repeated microtrauma or as atraumatic, without a known specific traumatic event. Especially for the classification of the atraumatic instability there is no accepted consensus in the orthopedic literature. In this investigation we have addressed the articular structures that contribute to the stability of the hip such as the bony components, the capsule, ligaments and labrum.

In this article imaging findings associated with joint distraction using a traction force well below the forces needed to distract a normal hip joint were analyzed. Arvidsson reported that a traction force of over 400 N is needed to distract the hip joint [6]. Distraction of the hip joint with fluid improves the visibility of the cartilage surface, and joint distension forces between 200 and 250 N are needed [7]; thus, cartilage defects might be detected more easily. In our study traction MR arthrography with 80–100 N yielded a joint space distraction in 8 % of all included hips.

Manual traction during radiography has been used previously to make a distraction between the femoral head and acetabulum [28, 29]. MR arthrography with continuous leg traction is a feasible and safe procedure that improves visualization of labral tears [30] and the femoral and acetabular cartilage [31, 32]. The vacuum force accounts for half of the total force needed for a hip joint distraction [7].

Cases with full thickness cartilage defects had to be excluded because in these cases it was impossible to differentiate whether the contrast layer visible between the acetabular and femoral surface was caused by a positive distraction or the full thickness cartilage defects.

The present study demonstrates that patients with positive joint distraction at traction MR arthrography have significantly higher neck-shaft angles, smaller CE angles, smaller acetabular depth, higher alpha angle and a thicker ligamentum teres compared to patients without distraction. The significant findings in the present study correlate with MR findings in developmental hip dysplasia (small CE angles [9], small acetabular depth [33] and increased neck-shaft angles), which is certainly associated with instability of the hip.

Osseous deformities at the femoral head-neck junction, quantified as higher alpha angle in patients with positive joint distraction, may be a contributing factor to the microinstability. The reduced depth of the femoral waist seems to lead to leverage out of the acetabulum and thus a subtle subluxation. Its has been reported in the literature that athletes with femoroacetabular impingement often need to use

Table 2 Soft tissues: quantitative criteria

a

	Observer 1			Observer 2			ICC	
	Control group (mean±SD)	Study group (mean±SD)	p-value	Control group (mean±SD)	Study group (mean±SD)	p-value	Control group	Study group
Coronal thickness ligamentum teres [mm]	4.7±1.4	5.4±1.8	<0.05	4.2±1.5	5.0±2.0	<0.05	0.79	0.85
Thickness SBILFL [mm]	6.0±1.5	6.1±1.8	0.78	5.9±1.2	5.9±1.5	0.84	0.75	0.87
Thickness IBILFL [mm]	4.5±1.2	4.3±1.0	0.25	4.6±1.2	4.3±0.9	0.06	0.81	0.74
Ap transverse zona orbicularis [mm]	7.1±1.6	6.6±1.7	0.12	7.1±1.5	6.8±1.7	0.20	0.82	0.84
Thickness of iliopsoas tendon [mm]	4.4±0.9	4.3±0.9	0.67	4.5±0.8	4.1±0.6	<0.05	0.84	0.71
Labral size [mm]								
Anterior	7.1±2.4	7.0±2.0	0.94	6.8±2.2	7.3±1.7	0.23	0.84	0.85
Superior	6.0±1.8	6.5±2.5	0.37	6.4±2.0	7.1±2.4	0.10	0.76	0.86
Posterior	5.4±1.3	5.9±1.4	0.06	5.6±1.3	5.9±1.5	0.30	0.81	0.74

b

	Observer 1			Observer 2			Kappa values	
	Control group	Study group	p-value	Control group	Study group	p-value	Control group	Study group
Abnormal ligamentum teres	28 % (14/50)	34 % (17/50)	0.67	28 % (14/50)	42 % (21/50)	0.21	0.70	0.66
Iliopsoas tendonitis	0 %(0/50)	0 % (0/50)	1.00	0 % (0/50)	0 % (0/50)	1.00	n/a	n/a
Iliopsoas bursitis	4 % (2/50)	0 % (0/50)	0.50	0 % (0/50)	0 % (0/50)	1.00	n/a	n/a
Labral lesion								
Anterior	66 % (33/50)	62 % (31/50)	0.84	60 % (30/50)	62 % (31/50)	1.00	0.45	0.92
Superior	44 % (22/50)	38 % (19/50)	0.69	22 % (11/50)	28 % (14/50)	0.65	0.44	0.78
Posterior	12 % (6/50)	14 % (7/50)	1.00	8 % (4/50)	10 % (5/50)	1.00	0.56	0.43

a range of motion for their hip that is greater than their physiological motion, which is limited by the cam deformity. The conflict between the cam deformity and the acetabular rim results in levering of the femoral head posteriorly [34]. This mechanism may damage the acetabular rim structures with a subsequent acetabular rim fracture or tear of the labrum or capsule, similar to a bony Bankart lesion of the shoulder [35]. Interestingly, it was reported that 9 of 14 patients with a hip dislocation had evidence of femoroacetabular impingement, 8 with cam deformities [36]. However, as opposed to our study, the patients described above suffered from traumatic hip dislocation. It is impossible to differentiate whether arthroscopically reported chondral defects and bodies result from dislocation or impingement.

Soft tissues seem to play a major role in the development of atraumatic instability of the hip joint. Connective tissue disorders such as Ehlers-Danlos or Marfan syndrome may lead to instability of the hip joint [37]. Ito et al. [27] state that the proximal to middle part of the hip joint capsule, which includes the zona orbicularis, seems to be a key structure for hip stability in distraction. General ligamentous laxity may lead to instability in the hip and other joints. The capsular ligaments, especially the iliofemoral ligament, are reported to be major stabilizers of the hip joint [38, 39]. In the present study, however, we could not find differences concerning the capsular ligaments between the two groups.

According to the literature, the ligamentum teres contributes to the stability of the hip joint [40]. Arthroscopy shows that the ligamentum teres is taut in external rotation and redundant in internal rotation [35]. In our study group the ligamentum teres was thicker than in the control group. One can speculate that the thicker ligamentum teres may be a mechanism of compensation (hypertrophy) resulting from instability. This is in line with reports of hypertrophy of the ligamentum teres in dysplastic hips [41]. The ligamentum teres may cicatrize because of repetitive microtrauma. Cerezal et al. [19] mentioned that a torn ligamentum teres might be a possible cause of microinstability.

Some authors speculated that labral tears may cause microinstability [25] and in reverse labral tears may be caused by microinstability [26]. The results of the present instability model however show that labral lesions in patients with positive joint distraction are not more frequent than in patients without joint distraction.

The recent literature reports that impingement surgery may lead to instability of the hip joint[42, 43]. Surgical intervention at the acetabular rim, such as resection of the labrum or trimming the osseous acetabular rim, should be performed with caution in patients with hips that are at risk for instability. Therefore, diagnostic criteria to identify these hips at risk are crucial to prevent a decompensation of the hip instability. Atraumatic instability is treated non-surgically with adaptation of the physical activity or physical therapy. Intraarticular anesthetic or corticosteroid injection may be helpful as well [35]. Surgery is rarely considered when nonsurgical treatment is not successful. Surgery may include the repair of an acetabular labral tear, capsulorrhaphy or suture plication of the capsule [35, 44, 45].

There are several study limitations to be considered. The study population was older than the usual population undergoing FAI surgery. Because of the retrospective nature of the study, it was not possible to obtain more detailed clinical information, for example, whether the patient has general joint laxity. Further, it is not proven that axial traction is an appropriate model for laxity, since the other directions, anterior-posterior and medial-lateral, are not tested. However, it is difficult to test the anterior-posterior and medial-lateral translation in a reproducible way and to image patients under stress to the hip joint in these directions. All measurements in the study were performed with axial traction of the hip joint. Images without traction were not available for analysis. Joint distraction might have an effect on the shape and therefore on the measurements of the thickness of ligaments. The measurement of the CE angles may be affected by the joint distraction. A large joint distraction will lead to an underestimation of the CE angle. The average joint space distraction was 0.8 mm. A simulation showed that moving the center of the hip joint 0.8 mm distally resulted in a small change in the CE angle of around 0.9° (range 0.4–1.3°), which was in the range of interobserver variability.

We conclude that increased neck-shaft angles, small CE angles, small acetabular depth, higher alpha angles and a thick ligamentum teres are associated with positive hip joint distraction.

Conflicts of interest The authors declare that they have no conflict of interest.

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